Analysis of Hand Anthropometric Dimensions of Male Industrial Workers of Haryana State

Arunesh Chandra *chandra_arunesh@yahoo.co.in*
Faculty of Engineering/Mechanical
Engineering Department/
Krishna Institute of Engineering & Technology
Ghaziabad, UttarPradesh, 201206, India

Pankaj Chandna *pchandna08@gmail.com*
Faculty of Engineering/Mechanical
Engineering Department/
National Institute of Technology
Kurushetra, Haryana, 136119, India

Surinder Deswal *sdeswal@nitkkr.ac.in*
Faculty of Engineering/Civil
Engineering Department/
National Institute of Technology
Kurushetra, Haryana, 136119, India

Abstract

The purpose of this paper is to analyse the thirty-seven hand anthropometric characteristics of the industrial worker of the Haryana state. A survey of convenience sample of eight hundred and seventy eight male industrial workers was conducted in the year 2009. Paper contains data from all the four divisions of Haryana state of India and from the five age groups. Minimum, maximum, mean, standard deviation, skewness, coefficient of variation, 5^{th}, 50^{th}, and 95^{th} percentile for each hand anthropometric dimension were calculated for the entire state. The normality assumption was evaluated for each hand dimension, separately. It was found that in most hand dimensions there were differences between five age groups. Additionally, the statistical analysis was carried out to correlate various hand dimensions and to obtain prediction equation between different variables. It has been found that most of the hand dimensions are correlated significantly with each other. The data gathered may be used for the design of hand tools, gloves, machine access spaces and hand-held devices and for selection of hand tools for use by Industrial worker working in the Haryana state of India.

Keywords: Hand Anthropometric Measurements, Industrial Worker, Hand Tools, Prediction Equation

1. INTRODUCTION

The economic growth and technological improvements have lead to greater demand and development of machines and devices used in industrial settings. With these dramatic changes there has also been greater interaction between man and machines. Anthropometric data are one of essential factors in designing machines and devices as described by [1 & 2]. Incorporating such information would yield more effective designs, ones that are more user friendly, safer, and enable higher performance and productivity. According to [3 & 4] the lack of properly designed machines and equipments may lead to lower work performance and higher incidence to work related injuries [5] have discussed that for years, anthropometry has been used in national sizing surveys as an indicator of health status. Anthropometric measurement of human limbs plays an important role in design of workplace, clothes, hand tools, manual tasks or access spaces for the hand and many products for human use.

Many studies have been conducted in the past to study the hand anthropometry. The depth and breadth of each segment of the hand were measured at points that were spaced at equal distance between the joints of the hand by [6]. Data on the mean length of the proximal and middle phalangeal segments for the fingers was published by [7]. Also [8] described that the interaction of handle size and shape with the kinematics and anthropometry of the hand have a great effect on hand posture and grip strength. Anthropometric survey measuring 18 dimensions of the right hand female workers living in Western Nigeria was conducted by [9] and the means of the collected data were compared with those females from USA, UK and Hongkong. Grip tasks for six subjects were studied using the hand measurement system by [10] the result showed that the flexion angle for the five fingers decreased with increasing grip span. [11 & 12] have stressed the importance of interplay of hand anthropometry and handle size or shape in influencing hand posture, grip span or grip strength. [13] estimated internal biomechanical loads of the hand from external loads and finger lengths that were themselves estimated from measured hand length and breadth; and found that hand anthropometric measurements, especially palm width, are better predictors of hand strength than stature and body weight. The effects on hand grip forces by relatively small changes in hand or handle size have also been demonstrated by [14] for torquing on cylinders [15] for gripping cylinders and [16] for gripping and squeezing on parallel handles of a standard handgrip dynamometer. Hence, measurement of small difference in hand size is important in understanding gripping forces. An important implication of the above discussion is that the anthropometry of the hand must be known for any target population for whom hand tools and other manual devices are to be designed. [17] stated that today, there is a growing demand among professional hand tool users to have ergonomically designed product. Further [18, 19 & 20] have discussed that poor ergonomic hand tools design is a well known factor contributing to biomechanical stresses and increasing the risk of cumulative trauma and carpal tunnel syndrome disorders of users. According to [21]) hand anthropometry is useful for determining various aspects of industrial machineries so as to design the equipment and machines for better efficiency and more human comfort. [22] discussed the potentially harmful effects of ignoring anthropometric differences between populations may be manifested when a developing nation, for example, imports equipment from a developed nation since the latter tends to design their equipment based on the anthropometric data of their own population. Reliable data on the association between hand injuries or disorders and hand anthropometry are almost absent in the developing countries. According to [23 & 24] the continued reliance on muscular power in tool use, in developing countries, and the widespread use of hand tools that do not fit the hands properly results in problems of health, safety and task performance. Further data on relevant anthropometric dimensions of the populations of the importing countries for equipment design may help alleviate the problems. Only a limited work has been reported in connection of hand anthropometry data for the populations of developing countries by [25, 26, 27, 28, 29 & 30].

Keeping the above-mentioned factors in consideration, the present analysis is an attempt to study the impact of collected hand anthropometric data of male industrial worker of Haryana state. As Haryana state of India has total geographical area of 44212 sq. meters. As per Census data 2001 male population of state is 11364000 with about total 498656 (5%) of male population working in almost about 72643 registered industrial units with output @ 6430 Crores with major SME (small manufacturing enterprises) clusters and SEZ (small economic zone) in the Haryana State of India. These movements and others provide incentives for foreign suppliers and investors to open factories and service sectors in Haryana state of India. Many of the industries being developed, therefore, would depend heavily on tools and equipment imported from IC (Industralized Countries) with the negative consequences as described above, if no attempt will be made to match equipment design with human characteristics. The present study thus represents an effort for analysing hand anthropometry data of male industrial worker. The data from this study will also help to understand the anatomical relationships among the various segments of the hand within the Haryana Industrial worker population.

2. METHODS

2.1 Subjects and Apparatus

Sets of thirty-seven hand dimensions were measured for each industrial worker. Selection of these dimensions were made on the basis of their relevance to the design of industrial tools, machine guarding and other manual equipments, and also because they have been measured in previous research studies in different populations. The figures of the hand dimensions are provided in figures 1(a) and 1(b). A total of 878-convenience sample of participants were measured from thirty-eight small and medium scale industries located in different divisions of the state. The range included companies from the automobile, tools and instruments, railway workshop, agricultural and metal sectors, among other, mainly located in the four different divisions (Ambala, Rohtak, Gurgaon and Hisar) of the Haryana state of the India. Subjects were selected according to their availability and willingness to participate without payment or any other kind of reward they were informed with the objectives of the study, anthropometric dimensions, clothing requirements, measurements procedures and freedom to withdraw. Age of the subjects varied between 18 and 62 years old with an average age of 37.91 years, whereas average stature height and body weight of the subjects was found out to be 1653.23 mm and 65.14 kg respectively. The sample comprised essentially individuals from industry. Underlying the choice of subjects from industry is the fact that this account for approximately 5% of active adult male population of Haryana state (Census, 2001). The methods of hand anthropometric measurements were same as stated by [31 & 32]. Regular measurement tools are used such as Hardenpen anthropometer for stature measurement and arm length measurement, small anthropometer for elbow length measurement, digital vernier caliper for length, breadth and depth measurement of hand, measuring tape for circumferential measurements, a wooden cone designed locally and specially to measure internal grip diameter, inner caliper for measurement of grip span and the body weight was measured by portable weighing digital scale. Table 1 describes the age distribution of the sample of the subjects measured.

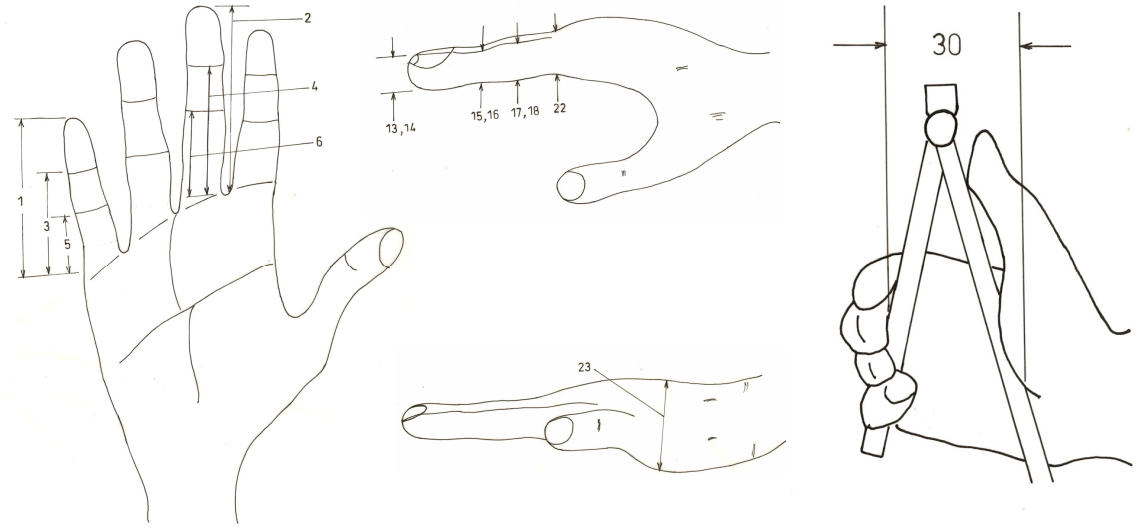

FIGURE 1(A): Selected right hand Anthropometric dimensions of Male Industrial worker Defined In Table 3

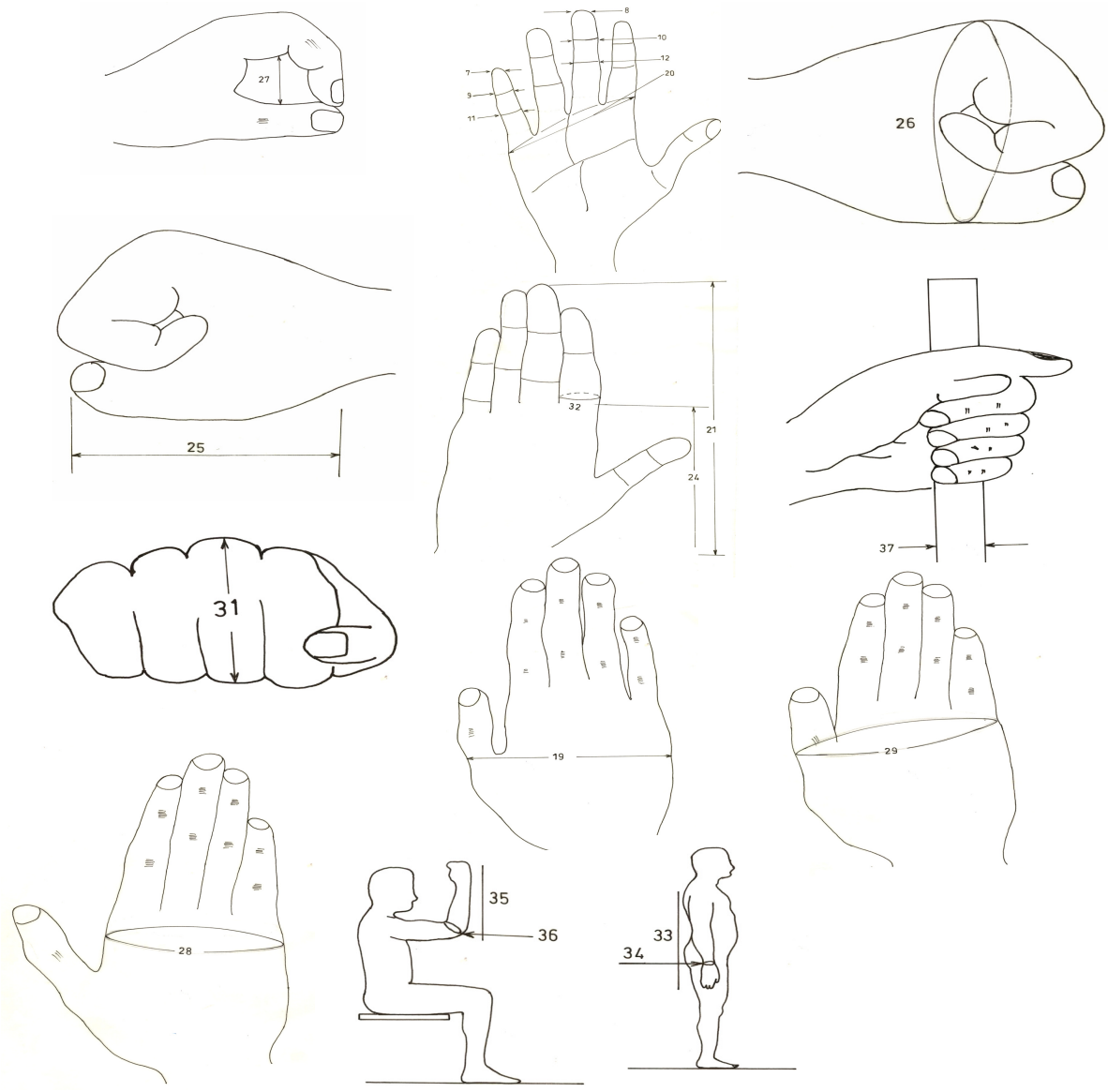

FIGURE 1(B): Selected right hand Anthropometric dimensions of Male Industrial worker Defined In Table 3

Age Group (Years)	Male Industrial Worker	
	Number	Percentage
18 – 25	133	15.15
26 – 35	253	28.82
36 – 45	221	25.17
46 – 55	218	24.83
56-Above	53	6.04

TABLE 1: Age distribution of Subjects

3. RESULTS

According to [33 & 34] there are many factors in human measurements that intervene as sources of error and results can be systematically different in spite of the measures being highly trained.

In anthropometric research the measurer cannot perceive the anomalous measures, as the norm has a very wide range and the size differences among the subjects of a sample are much higher than the accuracy of experimental devices, sometimes a factor of 10 or higher. Thus the data collected was further analyzed using SPSS statistical package (version 16.0) for normality distribution of each hand dimension, using the Kolmogorov-Smirnov and using the Shapiro-Wilk test at the 5% level of significance, the results of the tests are shown in table 2. Outputs are also obtained from box-plots generated from the explore command and the extreme outliers that is 1.77% of the collected readings are rejected for further analysis as they are not following the normal distribution curve as these may be systematic or bias errors which are possible which may not be clearly noticeable and occasionally these may be systematic errors in the measurement processes which could have a significant effect on both mean values of experimental variable and their standard deviation could cause mistaken conclusions over considered population.

S.No.	Measured Parameter	Kolmogorov Smirnov		Shapiro-Wilk	
		Statistic	Significance	Statistic	Significance
1	Age	0.072	0.000	0.975	0.000
2	Stature height	0.069	0.000	0.971	0.000
3	Weight	0.052	0.004	0.993	0.030
4	Finger tip to root digit 5	0.041	0.056	0.994	0.042
5	First joint to root digit 5	0.039	0.092	0.994	0.063
6	Second joint to root digit 5	0.049	0.009	0.991	0.008
7	Finger tip to root digit 3	0.063	0.000	0.982	0.000
8	First joint to root digit 3	0.039	0.083	0.991	0.004
9	Second joint to root digit 3	0.048	0.011	0.991	0.006
10	Breadth at tip digit 5	0.035	0.200	0.992	0.013
11	Breadth at first joint digit 5	0.044	0.032	0.993	0.035
12	Breadth at second joint digit 5	0.045	0.025	0.991	0.005
13	Breadth at tip digit 3	0.032	0.200	0.995	0.124
14	Breadth at first joint digit 3	0.050	0.007	0.990	0.003
15	Breadth at second joint digit 3	0.045	0.025	0.991	0.005
16	Depth at tip digit 5	0.055	0.002	0.987	0.000
17	Depth at first joint digit 5	0.042	0.044	0.994	0.075
18	Depth at second joint digit 5	0.070	0.000	0.977	0.000
19	Depth at tip digit 3	0.051	0.006	0.993	0.026
20	Depth at first joint digit 3	0.044	0.031	0.989	0.001
21	Depth at second joint digit 3	0.044	0.032	0.990	0.002
22	Grip span	0.051	0.006	0.994	0.066
23	Max. breadth of the hand	0.092	0.000	0.978	0.000
24	Breadth of the knuckles	0.079	0.000	0.984	0.000
25	Hand length	0.084	0.000	0.986	0.000
26	Palm length	0.077	0.000	0.989	0.002
27	Depth of the knuckles	0.136	0.000	0.963	0.000
28	Max. depth of the hand	0.070	0.000	0.989	0.002
29	Fist length	0.105	0.000	0.987	0.000
30	First phalanx digit 3 length	0.105	0.000	0.967	0.000
31	Fist circumference	0.064	0.000	0.991	0.007
32	Hand circumference	0.072	0.000	0.988	0.000
33	Max. hand circumference	0.057	0.001	0.990	0.003
34	Index finger circumference	0.127	0.000	0.972	0.000
35	Wrist circumference	0.087	0.000	0.990	0.003
36	Arm length	0.077	0.000	0.982	0.000
37	Elbow length	0.050	0.006	0.986	0.000
38	Elbow flexed	0.070	0.000	0.989	0.001
39	Max. internal grip diameter	0.175	0.000	0.934	0.000

40	Middle finger palm grip diameter	0.196	0.000	0.913	0.000

TABLE 2: Comparison of the empirical distribution of the sample vs. the theoretical (Normal) distribution for Male Industrial Worker

With consideration of normal distribution table 3 provides the minimum, maximum, mean, standard deviation, coefficient of variation, skewness of each hand dimension and the values of each hand dimension at the 5^{th}, 50^{th}, and 95^{th} percentile.

S. No	Hand dimensions	Min.	Max.	Mean	SD	CV	Skewness	Percentile		
								5^{th}	50^{th}	95^{th}
1	Finger tip to root digit 5	49.79	68.10	59.13	3.39	5.73	-0.117	52.97	59.95	66.89
2	First joint to root digit 5	27.31	41.58	34.23	2.76	8.06	-0.040	28.16	34.37	39.33
3	Second joint to root digit 5	12.93	22.55	17.52	1.96	11.19	0.046	14.12	17.45	21.53
4	Finger tip to root digit 3	69.79	90.80	79.05	4.31	5.45	0.384	71.44	79.18	88.41
5	First joint to root digit 3	43.76	60.51	52.06	3.54	6.80	0.091	45.13	52.51	59.36
6	Second joint to root digit 3	19.46	32.41	25.53	2.71	10.61	0.139	21.24	25.72	30.52
7	Breadth at tip digit 5	10.62	15.84	12.97	1.04	8.02	0.021	11.22	13.13	15.28
8	Breadth at first joint digit 5	12.72	17.60	15.10	0.93	6.16	-0.024	13.53	15.27	17.14
9	Breadth at second joint digit 5	14.73	19.79	17.06	0.99	5.80	0.276	15.50	17.17	19.26
10	Breadth at tip digit 3	12.85	18.56	15.79	1.12	7.09	-0.082	13.54	16.02	18.07
11	Breadth at first joint digit 3	15.07	19.64	17.35	0.90	5.19	0.191	15.76	17.49	19.53
12	Breadth at second joint digit 3	17.90	22.45	20.21	0.94	4.65	0.187	18.37	20.27	22.23
13	Depth at tip digit 5	9.46	13.86	11.37	0.86	7.56	0.293	10.02	11.53	13.45
14	Depth at first joint digit 5	11.22	16.31	13.70	0.99	7.23	0.078	12.06	13.78	15.84
15	Depth at second joint digit 5	13.84	19.97	16.50	1.24	7.51	0.388	14.57	16.55	19.32
16	Depth at tip digit 3	10.32	15.35	12.99	0.98	7.54	-0.103	11.39	13.17	14.99
17	Depth at first joint digit 3	12.83	17.85	15.51	1.13	7.29	-0.036	13.60	15.69	17.84
18	Depth at second joint digit 3	16.53	22.30	19.08	1.13	5.92	0.310	17.40	19.18	21.47
19	Grip span	82.32	114.66	98.07	6.30	6.42	-0.019	86.71	99.15	109.56
20	Max. breadth of the hand	95.00	110.00	101.83	3.38	3.32	0.278	95.00	102.00	110.00
21	Breadth of the knuckles	78.00	92.00	84.85	2.82	3.32	0.082	80.00	85.00	92.00
22	Hand length	170.00	202.00	185.77	6.32	3.40	0.216	175.00	187.00	201.00
23	Palm length	94.00	118.00	105.59	4.57	4.33	0.188	97.00	106.00	115.00
24	Depth of the	24.00	32.00	28.04	1.68	5.99	0.010	25.00	28.00	31.00

	knuckles									
25	Max. depth of the hand	35.00	54.00	44.62	3.41	7.64	0.071	40.00	45.00	51.00
26	Fist length	89.00	113.00	100.05	4.99	4.99	0.009	92.00	101.00	110.00
27	First phalanx digit 3 length	60.00	74.00	65.85	2.92	4.43	0.442	62.00	66.00	72.00
28	Fist circumference	252.00	305.00	277.65	10.57	3.81	-0.093	259.00	280.00	305.00
29	Hand circumference	225.00	265.00	243.82	8.52	3.49	-0.100	228.00	245.00	262.00
30	Max. hand circumference	310.00	379.00	344.50	12.87	3.74	-0.251	319.00	346.00	373.00
31	Index finger circumference	60.00	77.00	67.28	3.76	5.59	-0.075	61.00	68.00	74.00
32	Wrist circumference	149.00	185.00	164.54	6.92	4.21	0.153	152.00	165.00	180.00
33	Arm length	692.00	847.00	771.16	27.36	3.55	-0.025	727.00	776.00	821.00
34	Elbow length	423.00	501.00	459.91	15.70	3.41	0.260	434.00	462.00	493.00
35	Elbow flexed	223.00	320.00	263.72	18.11	6.87	0.113	234.00	266.00	295.00
36	Max. internal grip diameter	35.00	52.00	42.68	4.05	9.49	0.163	35.00	44.00	50.00
37	Middle finger palm grip diameter	12.00	22.50	16.33	2.47	15.12	0.188	12.50	17.50	21.00

TABLE 3: Hand Anthropometric data of sample (N=878, All measurements are in Millimeter)

In addition to the above analysis the male industrial worker groups were divided further into five age groups of 18-25, 26-35, 36-45, 46-55, and above 56 years, for which mean and standard deviations, were calculated separately as shown in table 4. Based on these values, the 5^{th}, 50^{th} and 95^{th} percentiles can be calculated separately.

S. No	Hand dimensions	18-25 (n=133)		26-35 (n=253)		36-45 (n=221)		46-55 (n= 218)		56-Above (n= 53)	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	Finger tip to root digit 5	60.71	3.79	60.12	4.00	59.75	4.51	59.37	3.47	58.16	4.06
2	First joint to root digit 5	35.49	3.05	34.78	2.48	34.13	3.37	34.06	3.47	33.35	2.78
3	Second joint to root digit 5	18.14	2.23	17.81	1.85	17.64	2.31	17.36	1.96	16.82	2.00
4	Finger tip to root digit 3	79.95	4.58	80.06	5.31	79.16	4.81	79.77	4.98	77.19	5.49
5	First joint to root digit 3	52.92	3.51	53.48	3.97	51.98	4.06	52.05	3.67	49.62	4.84
6	Second joint to root digit 3	26.14	2.62	26.25	3.07	25.52	2.38	25.93	2.63	23.49	3.24
7	Breadth at tip digit 5	12.82	1.19	12.87	1.26	13.20	1.20	13.69	1.09	13.28	1.25
8	Breadth at first joint digit 5	15.03	1.01	15.03	1.02	15.34	1.03	15.64	1.13	15.36	1.11
9	Breadth at second joint digit 5	16.74	0.96	16.80	1.04	17.28	1.07	17.75	1.04	17.81	1.23
10	Breadth at tip digit 3	15.36	1.38	15.76	1.49	16.12	1.18	16.50	1.26	15.94	1.14
11	Breadth at first joint digit 3	17.13	0.98	17.19	1.14	17.58	1.08	18.02	1.09	17.71	1.13
12	Breadth at second joint	19.80	1.21	20.08	1.17	20.44	1.18	20.62	1.10	20.08	1.18

	digit 3										
13	Depth at tip digit 5	11.24	0.82	11.40	1.01	11.56	1.13	11.92	0.99	11.98	0.87
14	Depth at first joint digit 5	13.40	0.93	13.61	1.00	13.84	1.42	14.41	1.04	14.01	0.89
15	Depth at second joint digit 5	16.11	1.14	16.47	1.58	16.84	1.63	17.15	1.21	16.91	1.22
16	Depth at tip digit 3	12.76	0.97	12.88	1.13	13.25	1.03	13.52	1.08	13.38	1.09
17	Depth at first joint digit 3	15.30	0.97	15.31	1.30	15.84	1.33	16.10	1.25	16.32	1.07
18	Depth at second joint digit 3	19.00	1.24	18.92	1.19	19.31	1.23	19.75	1.35	19.66	0.92
19	Grip span	99.93	6.58	98.08	7.08	98.54	6.60	99.38	6.72	94.64	5.04
20	Max. breadth of the hand	101.41	4.51	101.85	4.11	102.68	3.80	103.54	4.26	102.26	4.30
21	Breadth of the knuckles	84.56	3.24	85.26	3.19	85.61	3.48	86.21	3.84	85.08	3.95
22	Hand length	186.41	8.32	187.25	8.28	188.30	7.96	188.10	7.88	182.82	7.52
23	Palm length	107.40	5.12	105.39	5.25	106.40	5.19	106.21	5.61	102.46	5.46
24	Depth of the knuckles	27.43	1.71	27.64	1.68	28.59	1.82	28.46	2.01	27.88	2.00
25	Max. depth of the hand	43.96	3.12	44.08	3.17	45.76	3.73	46.24	4.01	44.46	2.66
26	Fist length	99.79	5.87	100.39	6.03	101.13	5.18	101.52	4.92	99.25	4.67
27	First phalanx digit 3 length	66.48	3.15	66.56	3.62	66.13	2.98	66.69	2.99	65.23	3.07
28	Fist circumference	275.41	11.14	277.65	13.33	281.00	13.08	284.39	13.42	278.98	15.97
29	Hand circumference	242.08	10.22	243.44	10.84	247.99	9.29	248.37	11.52	239.94	10.21
30	Max. hand circumference	342.91	13.59	344.92	17.97	348.32	13.63	347.83	18.22	345.77	17.27
31	Index finger circumference	65.52	3.90	66.27	3.74	68.82	3.34	69.59	3.92	68.24	3.34
32	Wrist circumference	161.59	7.06	163.65	7.50	167.14	7.56	168.72	8.84	165.18	9.87
33	Arm length	772.81	30.49	777.05	33.50	773.12	31.06	773.60	27.53	768.04	27.73
34	Elbow length	463.21	17.58	462.43	20.93	462.61	16.20	463.50	16.87	456.50	13.91
35	Elbow flexed	262.79	19.78	263.30	18.24	268.10	16.29	267.75	20.13	267.64	19.92
36	Max. internal grip diameter	43.82	3.78	43.80	4.13	42.16	4.84	43.44	4.46	42.16	5.03
37	Middle finger palm grip diameter	17.09	2.69	16.87	2.67	16.21	2.79	16.17	2.65	15.51	2.26

TABLE 4: Hand Anthropometric data of sample classified by Age (Mean values and standard deviation) all measurements are in millimeter

Table 5 shows the correlation coefficients between different hand anthropometric dimensions. These coefficients were calculated to see to what extent these dimensions are related to each other and to what extent equipment design decisions could be based on such correlation. The simple and multiple regression analyses were done between hand length, hand circumference and other hand dimensions in order to find out the best set of predictors related to hand length and hand circumference and are provided in Table 6(a) and 6(b).

4. DISCUSSIONS

From 32486 measured hand variables, 578 measured readings are rejected using stem-and-leaf plots, histograms and box plots on SPSS software, based on the modifications of the Kolmogorov-Smirnov and Shapiro-Wilk test as it is suitable for continuous distribution to examine the test of normality distribution of data. Thus rejecting 1.77% (578) sample data which may due to certain type of error while measuring the hand dimensions the result obtains indicates that the hand variable have statistical distribution that can fit closely to normal distribution curve, as usual in from the result of the normality test given in Table 2. These test indicates that the thirty five out of thirty seven hand variables were normal with some deviation in other two variables, these two variable maximum internal grip diameter and middle finger palm grip diameter are also approximately normal ($p < 0.05$) knowing that a dimension is normal makes it possible to easily derive percentiles in the distribution using the standard normal (Z) table. Otherwise, the cumulative distribution may be used. The frequency distribution would look like a symmetrical bell-shaped or normal curve, with most subjects having values in the mid range and with a smaller number of subjects with high and low scores. As all the hand anthropometric dimensions follow a normal distribution curve and errors made in using the normal distribution are either not significant, statistically or are of little practical importance thus the probability density function of the underlying distribution is estimated based on a sample from the population without any prior knowledge of the mean, variance etc. of the population

Table 3 presents the summary data obtained for mean and standard deviation, as well as other important statistical information namely minimum, maximum, and coefficient of variation, skewness, and important percentile values for all the hand measurements of the male industrial worker. Coefficient of variation (the ratio of standard deviation to mean) among the thirty seven hand dimensions ranged from 3.32 to 15.12 % with 34 of them below 10% far lower than we can assume or suggested by [35]. As the skewness of all the thirty-seven hand dimension is less than plus or minus one (<+/- 1.0); thus hand dimension is atleast approximately normal and skewness is not significantly different from normal, and hence we can use the mean, standard deviation and different percentile values to easily determine the proportion of the population who fall within a specific range of value for a given hand dimension. These values may also be used for comparison with those published for other population.

The values of mean and standard deviation (SD) for five age groups of male industrial workers surveyed, namely 18-25, 26-35, 36-45, 46-55, and > 56 years; pertaining to thirty seven hand anthropometric dimensions were calculated and are presented in table 4. The data show an increase in most hand dimensions in the middle age before declining with an increasing age. This classification revealed that there are clear differences between the five groups. Moreover young and middle aged worker are smaller than 56 and above age industrial worker in breadth at second joint digit 5, depth at tip digit 5 and depth at first joint digit 3. However in other hand dimensions, the 56 and above age industrial worker are generally smaller than both the young and the middle aged. Figure 2 illustrate the average values obtained of hand length and hand circumference for five different age groups. This shows that, hand length and hand circumference vary significantly with age. These differences are very important and should be taken into consideration in designing the hand tools or equipment that should be controlled by hands of different age groups. [36] and many others researchers support these findings that anthropometric data have indicated difference among age groups. It will be interesting to find out whether these are significant difference between different age groups most of the hand dimensions with significant differences with were not related to vertebral compression. The exact reason for the significant differences remain unknown we could not identify them in this study. The differences found in the hand anthropometric dimensions of the different age groups emphasize the usefulness of this study and of the results presented herein.

Correlations among measured hand segments were performed among hand length and hand circumference. Testing the significance of correlation revealed that almost all values are significant and positively correlated between the hand length and hand circumference, suggest that it is possible to predict hand dimensions with 95% confidence, by measuring the hand length

and hand circumference alone. Linear regression equations are provided in Table 6(a) and 6(b) respectively. The statistically significant correlation between the hand lengths (L) related variables are coded by Y_1 to Y_{28} and the hand circumference (C) related variables are coded by Y_{29} to Y_{34}.

Code	Variable	Coefficient of Correlation	Prediction Equation
L	Hand length	-	-
Y_1	Finger tip to root digit 5	0.602**	$Y_1 = 0.4346L - 20.736$
Y_2	First joint to root digit 5	0.486**	$Y_2 = 0.3866L - 35.296$
Y_3	Second joint to root digit 5	0.299**	$Y_3 = 0.2098L - 21.258$
Y_4	Finger tip to root digit 3	0.697**	$Y_4 = 0.5322L - 18.892$
Y_5	First joint to root digit 3	0.610**	$Y_5 = 0.4082L - 23.512$
Y_6	Second joint to root digit 3	0.470**	$Y_6 = 0.2922L - 28.622$
Y_7	Breadth at tip digit 5	0.110*	$Y_7 = 0.12L - 8.9$
Y_8	Breadth at first joint digit 5	0.139**	$Y_8 = 0.1276L - 7.886$
Y_9	Breadth at second joint digit 5	0.181**	$Y_9 = 0.12L - 5.09$
Y_{10}	Breadth at tip digit 3	0.038	$Y_{10} = 0.1478L - 11.988$
Y_{11}	Breadth at first joint digit 3	0.168**	$Y_{11} = 0.125L - 6.03$
Y_{12}	Breadth at second joint digit 3	0.272**	$Y_{12} = 0.1518L - 8.458$
Y_{13}	Depth at tip digit 5	0.060	$Y_{13} = 0.0952L - 5.792$
Y_{14}	Depth at first joint 5	0.163**	$Y_{14} = 0.1292L - 9.452$
Y_{15}	Depth at second joint 5	0.152**	$Y_{15} = 0.1746L - 14.786$
Y_{16}	Depth at tip digit 3	0.022	$Y_{16} = 0.1188L - 8.688$
Y_{17}	Depth at first joint digit 3	0.141**	$Y_{17} = 0.1332L - 8.642$
Y_{18}	Depth at second joint digit 3	0.243**	$Y_{18} = 0.1386L - 6.046$
Y_{19}	Grip span	0.419**	$Y_{19} = 0.6674L - 24.464$
Y_{20}	Maximum breadth of the hand	0.466**	$Y_{20} = 0.46L + 17.4$
Y_{21}	Breadth of the knuckles	0.415**	$Y_{21} = 0.38L + 15.2$
Y_{22}	Palm length	0.290**	$Y_{22} = 0.6L - 6.0$
Y_{23}	Depth of knuckles	0.411**	$Y_{23} = 0.18L - 4.8$
Y_{24}	Maximum depth of hand	0.254**	$Y_{24} = 0.38L - 25.8$
Y_{25}	Fist length	0.306**	$Y_{25} = 0.58L - 5.8$
Y_{26}	First phalanx digit 3 length	0.455**	$Y_{26} = 0.34L + 4.6$
Y_{27}	Elbow length	0.607**	$Y_{27} = 1.9796L + 101.2653$
Y_{28}	Arm length	0.582**	$Y_{28} = 3.44L + 141.6$

TABLE 6(a): Coefficient of Correlation between Hand Length and related variables for Haryana State Industrial Workers and the corresponding prediction equation

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
1	1																																				
2	.833**	1																																			
3	.619**	.752**	1																																		
4	.649**	.516**	.312**	1																																	
5	.553**	.550**	.366**	.852**	1																																
6	.378**	.384**	.428**	.640**	.746**	1																															
7	.118**	-.043	.083	.089	-.009	-.006	1																														
8	.157**	-.043	.116**	.057	-.037	.040	.623**	1																													
9	.161**	.042	.143**	.174**	.066	.071	.511**	.684**	1																												
10	.029	-.091*	.055	-.014	-.171**	-.046	.556**	.562**	.404**	1																											
11	.086	.005	.098*	.098*	.025	.111*	.435**	.621**	.619**	.595**	1																										
12	.183**	.105*	.173**	.276**	.233**	.166**	.342**	.468**	.634**	.343**	.592**	1																									
13	.006	-.066	.002	.036	-.077	-.009	.516**	.513**	.534**	.441**	.480**	.507**	1																								
14	.148**	.014	.132**	.170**	.048	.188**	.416**	.513**	.543**	.294**	.417**	.501**	.545**	1																							
15	.219**	.069	.049	.211**	.072	.141**	.356**	.397**	.461**	.350**	.330**	.341**	.447**	.605**	1																						
16	-.050	-.174**	-.057	.000	-.093*	.017	.444**	.478**	.449**	.483**	.460**	.348**	.631**	.515**	.487**	1																					
17	.051	-.061	.025	.101*	.019	.157**	.309**	.500**	.488**	.318**	.535**	.490**	.451**	.596**	.528**	.553**	1																				
18	.160**	.073	.091	.240**	.186**	.218**	.234**	.362**	.443**	.268**	.517**	.572**	.442**	.555**	.502**	.489**	.662**	1																			
19	.179**	.165**	.027	.171**	.126**	.026	.061	-.085	-.032	-.036	.031	.093*	.173**	-.046	.104*	.058	.009	.083	1																		
20	.304**	.166**	.124**	.299**	.180**	.058	.339**	.362**	.355**	.335**	.315**	.273**	.291**	.224**	.286**	.251**	.257**	.273**	.262**	1																	
21	.250**	.135**	.145**	.389**	.265**	.262**	.326**	.366**	.368**	.345**	.297**	.338**	.371**	.303**	.364**	.302**	.304**	.272**	.181**	.668**	1																
22	.602**	.486**	.299**	.697**	.610**	.470**	.110**	.139**	.181**	.038	.168**	.272**	.060	.163**	.152**	.022	.141**	.243**	.419**	.466**	.415**	1															
23	.393**	.305**	.173**	.329**	.256**	.229**	.077**	.077**	.072	.000	.086**	.149**	.053	.115**	.095*	.017	.164**	.158**	.512**	.377**	.290**	.772**	1														
24	.192**	.073	.118**	.232**	.127**	.135**	.294**	.375**	.434**	.292**	.419**	.460**	.301**	.318**	.308**	.336**	.406**	.374**	.031	.398**	.411**	.254**	.204**	1													
25	.127**	.012	.021	.146**	.092*	.051	.273**	.301**	.384**	.370**	.392**	.398**	.271**	.269**	.212**	.216**	.289**	.346**	.069	.397**	.254**	.205**	.099*	.411**	1												
26	.378**	.294**	.226**	.390**	.413**	.365**	.201**	.180**	.343**	.045	.282**	.391**	.153**	.351**	.383**	.157**	.375**	.408**	.215**	.341**	.306**	.569**	.512**	.362**	.371**	1											
27	.578**	.436**	.278**	.735**	.632**	.423**	.180**	.166**	.300**	.084	.220**	.488**	.230**	.311**	.266**	.118**	.270**	.388**	.191**	.393**	.455**	.717**	.466**	.397**	.284**	.515**	1										
28	.144**	-.056	.010	.319**	.161**	.113**	.370**	.370**	.378**	.234**	.225**	.290**	.233**	.320**	.258**	.245**	.285**	.238**	.104**	.619**	.555**	.390**	.274**	.449**	.388**	.251**	.346**	1									
29	.265**	.082	.114**	.269**	.101*	.079	.432**	.427**	.452**	.463**	.375**	.383**	.371**	.379**	.315**	.314**	.309**	.307**	.125**	.770**	.649**	.388**	.278**	.525**	.596**	.372**	.394**	.682**	1								
30	.388**	.202**	.137**	.327**	.219**	.142**	.322**	.222**	.238**	.252**	.224**	.246**	.227**	.244**	.199**	.167**	.143**	.182**	.269**	.584**	.381**	.503**	.400**	.386**	.435**	.398**	.408**	.510**	.697**	1							
31	.152**	.031	.095*	.207**	.060	.046	.369**	.448**	.567**	.366**	.416**	.494**	.422**	.513**	.423**	.352**	.455**	.406**	.083	.467**	.463**	.242**	.172**	.549**	.547**	.391**	.374**	.496**	.631**	.354**	1						
32	.256**	.085	.156**	.288**	.135**	.124**	.315**	.364**	.513**	.328**	.330**	.456**	.277**	.409**	.328**	.224**	.290**	.359**	-.043	.561**	.506**	.284**	.093*	.473**	.486**	.301**	.373**	.592**	.709**	.450**	.603**	1					
33	.471**	.298**	.160**	.545**	.434**	.298**	.105*	.101	.114	.035	.107*	.138**	.043	.096*	.159**	.056	.103**	.194**	.303**	.382**	.365**	.607**	.440**	.168**	.202**	.295**	.514**	.309**	.391**	.436**	.100*	.294**	1				
34	.255**	.133**	.124**	.238**	.117**	-.028	.214**	.269**	.413**	.197**	.277**	.395**	.242**	.264**	.156**	.242**	.216**	.257**	.122**	.533**	.402**	.286**	.223**	.363**	.418**	.251**	.343**	.439**	.579**	.331**	.395**	.579**	.366**	1			
35	.408**	.390**	.191**	.517**	.475**	.270**	-.010	-.056	-.044	-.131**	-.021	.074	-.069	-.098*	-.008	-.175**	-.167**	.016	.383**	.318**	.153**	.585**	.365**	.013	.041	.216**	.359**	.185**	.121**	.334**	-.047	.133**	.446**	.052	1		
36	.290**	.227**	.034	.371**	.306**	.160**	-.004	-.051	-.019	-.111*	-.103*	.080	.024	.018	.099*	-.017	-.002	.032	.399**	0.181**	.120**	.400**	.233**	-.031	.052	.112*	.275**	0.103*	.046	0.231**	.039	.080	.248**	.017	.681**	1	
37	.481**	.297**	.179**	.549**	.442**	.351**	.110*	.071	.185**	-.025	.088	.237**	.048	.143**	.219**	.014	.153**	.251**	.264**	.347**	.320**	.582**	.463**	.226**	.206**	.432**	.580**	.279**	.382**	.424**	.158**	.280**	.799**	.336**	.369**	.220**	1

TABLE 5: Matrix of the Pearson Correlation Coefficients obtained between the different Hand Anthropometric dimensions as per order provided In Figure 1 and Table 3

**Correlation is significant at the 0.01 level (2- tailed) *Correlation is significant at the 0.05 level (2- tailed)

Code	Variable	Coefficient of Correlation	Prediction Equation
C	Hand circumference	-	-
Y_{29}	Maximum hand circumference	0.510**	$Y_{29} = 1.6552C - 65.1724$
Y_{30}	Index finger circumference	0.496**	$Y_{30} = 0.3621C - 19.569$
Y_{31}	Wrist circumference	0.509**	$Y_{31} = 0.8448C - 38.3276$
Y_{32}	Elbow flexed	0.391**	$Y_{32} = 1.7414C - 158.8793$
Y_{33}	Maximum internal grip diameter	0.121**	$Y_{33} = 0.431C - 63.5345$
Y_{34}	Middle finger grip diameter	0.046	$Y_{34} = 0.181C - 27.2845$

TABLE 6(b): Coefficient of Correlation between Hand Circumference and related variables for Haryana State Industrial Workers and the corresponding prediction equation

** Significant at α = 0.01 * Significant at α = 0.05
Note all dimensions in mm

The tests of hypothesis that the intercepts or the slopes are zero were rejected for the level of significance shown in Table 6(a) and 6(b) Predictions should be confined to the ranges of hand length and hand circumference as prescribed by the regression analysis. The minimum and maximum values for hand length were 170 mm and 202 mm respectively and the counter values for the hand circumference were 225 mm and 244 mm respectively. Although this hand anthropometric data will be of great value in practical application it should be noticed that these are static anthropometric measurers. Therefore, the use of such data in design of equipment, tools, and workstation in which functional hand anthropometric data is needed, must be done considering the differences between the two referred types of hand anthropometric data

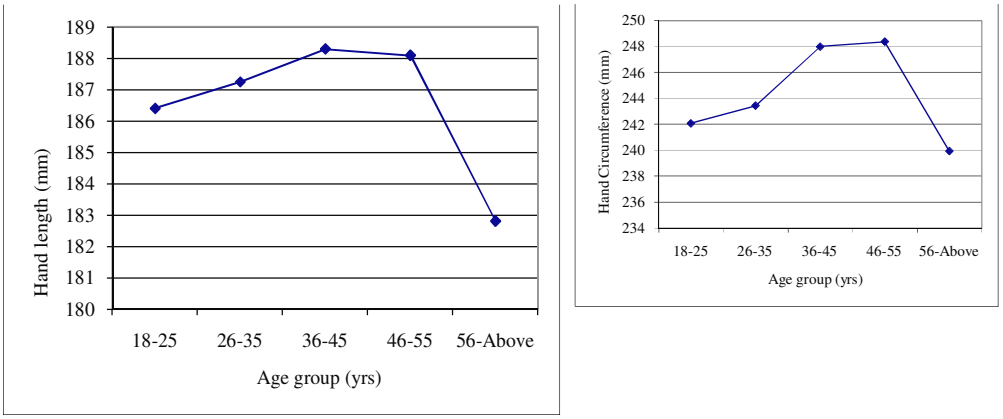

FIGURE 2: Variation of Hand Length and Hand Circumference (Mean Values in mm) for Age Groups (Yrs.) defined

5. CONCLUSIONS

Thirty-seven hand dimensions of eight hundred and seventy eight male industrial workers of Haryana state belonging to thirty-eight industries of Haryana state of India have been analysed in this work. This will be useful for the new designs/design modifications for hand tools, workstations, hand apparel, tools and protective equipment and other practical applications. Mean and standard deviation of the sample of different age groups shows that values of most of the hand anthropometric dimensions are higher in the middle age groups and lower with higher and lower age groups. With respect to the above analysis there are a few important remarks, which need to be emphasized.

- This study investigated assumptions of normality commonly made by designers in establishing workplace, equipment, as well as tool design recommendations and the objective of this analysis is to check precision in anthropometric measures. It was observed

that 98.23% of collected reading of 37 hand variables of hand anthropometric dimensions fit closely to a normal distribution curve.

- The correlation coefficients among different hand dimensions were calculated to see to what extent these dimensions are related to each other. It was observed that 77% of correlation coefficients are significant at the 1% level, 5% of the correlation coefficients are significant at 5% level, and 18% of the remaining values are insignificant. Correlation among measured hand segments was performed among hand length and hand circumference and almost all values are significant and positively correlated.
- The sample size used (878) was satisfactory for all variables. Therefore designers for industrial worker of Haryana state can utilize the statistics presented and prediction equations present in this study to set specifications for the system used, such as hand tools and other hand held devices. These prediction equations can be used to predict 34 hand variable dimensions with 95% confidence by measuring the hand length and hand circumference alone.
- There is a need to enlarge the sample size, not only in terms of age range, namely to compensate for low frequency observed below 25 and above 56 years, but also to encompass other occupational groups such as agricultural worker, household worker, constructional workers and of female workers as their numbers are increasing day to day in the state.

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